Space, time and size distribution of aerosols observed after dispersion of radioactive matter by an explosion

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Abstract. The results of space, time and size distribution of aerosols in the field tests, in which the short life-time radioactive substance (RaS) was released into the environment, are presented in this paper. The essential goal of the tests was to estimate distribution of the released RaS for different conditions and to elaborate the set of data applicable for testing of physical and/or mathematical models. The measurements of the activity concentrations in all tests showed that the majority of the dispersed RaS was present in the air above the monitored polygon only the first few minutes after the dispersion. The expected key dependence of activity distribution on the prevailing meteorological conditions at the time of RaS dispersion and shortly afterwards was confirmed. Size distribution of the aerosol was slightly bimodal, a large part of the activity was connected to the particles lying in the size interval (aerodynamic diameter) from 1.3 to 10.2 μm; activity median aerodynamic diameter (AMAD) was from 3 to 6.5 μm with geometric standard deviation (GSD) around 3 for the higher mode.

1. INTRODUCTION

During recent years, the problem of possible consequences of terroristic attacks with the abuse of ionizing radiation sources/radioactive substances has been widely discussed. So called “dirty bomb”, in which the release of the radioactive substances (RaS) is carried out with the help of a classical explosive is the most frequently discussed form of the probable radiological terroristic attack. In the Czech Republic (CR) we performed tests in an open area in which RaS (^{99m}Tc) was dispersed by the explosion of an industrial explosive. The main goal of these tests was to obtain reliable data sets and information on the distribution of surface contamination (horizontal and vertical) and activity and mass concentrations in air, which could be useful in testing models designed for evaluation of radiation situation near the point of RaS release [1]. The presented work summarizes results of space and time distribution of activity concentrations and size distribution of aerosol in the performed tests.

2. MATERIALS, METHODS AND TEST CHARACTERISTICS

All the tests were performed on the premises of the National Institute for Nuclear, Chemical and Biological Safety (NINCBS) Příbram – Kamenná based on the authorisation by the State Office for Nuclear Safety (SÚJB) and appropriate Mining Office.

^{99m}Tc was chosen due to its suitable physical characteristics: emission of 140 keV gamma-rays and its half-life of 6.01 h. Based on preliminary experiments carried out in the absence of the RaS, amount of 350 g of the industrial explosive was chosen. In first 2 tests the radionuclide was diluted into

1.5 litre of the carrier - a potassium permanganate aqueous solution in a cylindrical glass vessel; in the other tests the RaS carrier volume was of about 6 ml and the carrier was placed in a spherical glass container.

Directionality of the RaS dispersion was solved by the respective position of explosive and RaS and by situating the explosive and RaS carrier into a space delimited by steel plates (placed on the bottom, on the back and sides) surrounded by sandbags. The RaS release was performed in the most probable wind direction expected at the given site at an angle of about 30° to the horizontal plane. The selected meteorological quantities were measured with mobile automatic meteorological stations [1].

Eight tests were performed in all between years 2007-2010; 4 tests without an obstacle on the monitored area and 4 tests with an obstacle placed symmetrically to the y-axis in the most probable wind direction with the face wall 12m from the point of RaS dispersion. The obstacle dimensions were 11 m the width, 2.5 m the thickness and 3 m (1 test) or 6 m (3 tests) the height.

Monitoring points were spread on the area defined by the x- and y-coordinates x ± 20 m and y ϵ (- 5, + 50) m, respectively with y-axes in the most probable wind direction. For recording of the controlled explosion optical and infrared imaging techniques were used. Dose and dose rates in the contaminated area were measured by portable instruments with scintillation detectors. Surface activities were determined by means of collecting paper filters (passive sampling), which were arranged both horizontally on a polygon area, and vertically on vertical columns situated at selected sites and on all sides of the obstacle.

At up to 12 sites aerosols were sampled with the use of common sampling devices as well as with the use of cascade impactors serving for the determination of the aerosol particle size distribution. Aerosol samplers were placed in y-axis or symmetrically to it. In order to provide an estimate of the time distribution of the RaS dispersion at a given sampling site the aerosol filters (except those in the cascade impactors) were replaced 3 times with varying sampling intervals. ^{99m}Tc activities deposited on the filters were measured by semiconductor gamma spectrometry.

To determine temporal and spatial variation of aerosol concentration, up to 6 laser nephelometers (DustTrak) were used. The measurements were conducted with integration time of 1s in all the experiments. In some tests Aerodynamic Particle Sizer was used to determine temporal variation of aerosol size distribution.

3. RESULTS AND DISCUSSION

The detailed results of tests without an obstacle were published in [1]; the results of tests with an obstacle will be published soon. The dispersed activities were in the range 0.59 - 2.2 GBq. The total activities settled on the test polygon 40x55 m^2 were estimated in the range 34% - 36% of the total dispersed activity in the tests with 1.5 litre of the carrier and 0.2% - 11% in the tests with 6 ml of the carrier depending on the meteorological condition.

3.1 Activity concentration

Time course of the activity concentrations in the aerosols was similar in all the tests. As an example the results of one test with an obstacle are shown on Fig.1

and 2. All tests showed that the majority of the dispersed RaS is present in the air above the monitored polygon only during the first few minutes after the dispersion even if meteorological conditions were very stable. Then it usually dropped by several orders of magnitude, in some cases by more than 3 orders. Only in cases, where the sampling equipment was lying away from the real direction of RaS dispersion, the decrease of the activity between the first and second sampling was not so marked, but the maximum of the activity concentration measured in the first sampling was also significantly lower. In the time intervals following after the first one, activity concentrations did not change significantly. This result is important for the evaluation of potential radiological impacts and the organization of the response in emergency situations simulated in the tests.

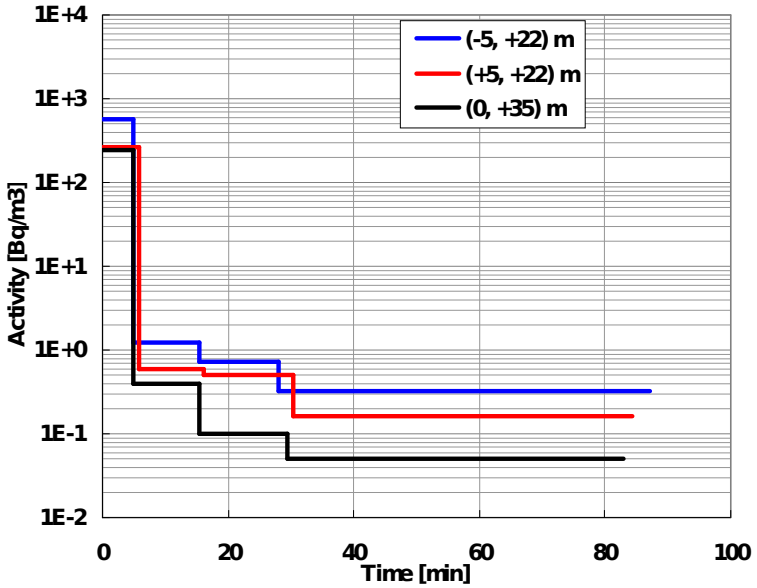

Figure 1 Time course of the activity concentration in the aerosols in one of the test with an obstacle for sampling points with coordinates (x,y) in m: (-5, +22), (+5,+22), (+0,+35)

Notices – Fig. 1:

- The obstacle was placed with the face wall of 12m from the point of RaS dispersion
- The sampling points (±5; +22) and (0; +35) are not directly visible from the point of RaS dispersion
- The activities are recalculated on 1 GBq of dispersed activity

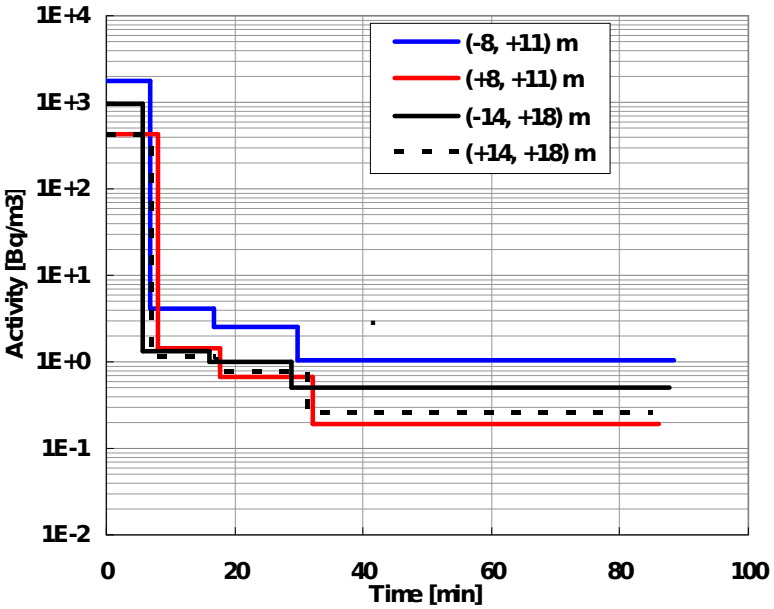

Figure 2 Time course of the activity concentration in the aerosols in one of the test with an obstacle for sampling points with coordinates (x,y) in m: (-8, +11), (+8,+11), (-14,+18), (+14,+18)

Notices – Fig. 2:

- The obstacle was placed with the face wall of 12m from the point of RaS dispersion
- The sampling points are directly visible from the point of RaS dispersion
- The activities are recalculated on 1 GBq of dispersed activity

The expected key dependence of activity distribution on meteorological conditions at the time of RaS dispersion and shortly afterwards was confirmed. Particularly the relation of wind direction and the direction of RaS propagation compelled by the blast wave was crucial. Significant deflections of real direction of aerosol propagation from the supposed direction due to meteorological condition prevailing at the time of dispersion were observed in some tests.

The samplings of aerosols were carried out only in a small number of points and the values of activities ranged within many orders, so it was not possible to observe differences in the activity concentrations in aerosols for tests with and without obstacles, although significant differences in passive sampling (fallout) were observed.

3.2 Aerosol size distribution

To determine the aerosols size distribution up to 4 cascade impactors were used (an 8-stage one and three 6-stage ones). All impactors were placed in supposed direction of the dispersion (x-axis distance = 0m).

The data were evaluated assuming a log-normal distribution of activities in dependence on the aerodynamic diameter (AD) of aerosols [2]. The parameters of the distribution were determined. Activity median aerodynamic diameter (AMAD) and geometric standard deviation (GSD) were estimated from the parameters of supposed distribution. AMAD and GSD were estimated excluding the smallest fraction of particles captured on a back-up filter (for 6 stage impactor particles with AD less than 0.39 μm, for 8 stage impactor particles

with AD less than 0.25 μm). In some cases observable bimodality of distribution at the boundary between the smallest fraction and the next one was the reason for the exclusion of the smallest fraction.

At small distances from the point of the explosion (y = 7m), the distribution was shifted to larger particles in comparison with other sampling sites. In tests without obstacles AMAD was almost 2 times higher at the distance y= 7 m than at longer distances: it was 6.5 μm (in average), while at longer distances it was from 3 to 4 μm. GSD was around 3. In tests with an obstacle AMAD was also 6.5 μm at a distance of 7 m, but at longer distances (beyond of the obstacle) AMAD was higher than in the tests without obstacles; the difference is approximately 1.5 μm; however the observed difference can still be caused by an uncertainty of AMAD determination.

The fraction of the activity attached to the smallest particles varies: in the smallest distance from the dispersion (y = 7 m) the fraction (AD < 0.25 μm) was less than 2% of the total activity, at larger distances the fraction (AD < 0.39 μm) was typically from 10% to 30%.

The size distributions of aerosols correspond to industrial aerosols (a large fraction of particles falls into the interval from 1.3 to 10.2 μm) with a relatively high GSD value.

4. CONCLUSIONS

The measurements of activity concentrations in all tests showed that the majority of the dispersed RaS was present in the air above the monitored polygon only during the first few minutes after the dispersion. Then the activities usually dropped by several orders of magnitude, in some cases by more than 3 orders. This result is important for the evaluation of potential radiological impacts and the organization of the response in emergency situations simulated in the tests.

The anticipated key dependence of activity distribution on the prevailing meteorological conditions at the time of RaS dispersion and shortly afterwards was confirmed.

The size distributions of aerosols corresponded to industrial aerosols, a large part of the activity was connected to the particles lying in the size interval from 1.3 to 10.2 μm, AMAD was from 3 to 6.5 μm with GSD around 3, when the smallest particles were excluded. The fraction of the smallest particles (less than 0.25 μm) was less than 2% of the total activity for the distance y=7m from the point of explosion, at larger distances the fraction of the smallest particles (less than 0.39 μm) was usually from 10% to 30%.

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